

1   **What is claimed is:**

2           1.     A system for monitoring fluids in a fluid processing system comprising:

3                   at least one ultrasound probe comprised of an emitting transducer and a receiving  
4           transducer;

5                   a signal processing unit attached to said at least one ultrasound probe, said unit  
6   comprised of at least a function generator, a dual channel analog-to-digital converter, and an  
7   interface processor;

8                   a computing system adjacent to said signal processing unit, said computing  
9   system receiving digitized signal information from said signal processing unit; and

10                  a thermistor attached to said signal processing unit to measure the temperature of  
11   said fluid;

12                  wherein, said function generator generates a power signal to activate said emitting  
13   transducer to emit an ultrasound wave of specific frequency over a specific time period  
14   repeatedly through said fluid to be received as a receiving signal by said receiving transducer;

15                  wherein, said analog-to-digital converter digitizes said power signal as an  
16   excitation signal at a specific sampling frequency;

17                  wherein, said analog-to-digital converter digitizes said receiving signal received  
18   by said receiving transducer at a specific sampling frequency;

19                  wherein, said computing system computes transmission time and phase shift  
20   between said excitation and receiving signals; and

21                  wherein, said computing system uses said phase shift measurement to compute  
22   sound velocity, density, compressibility, and solute concentration measurements of the fluid at a  
23   measured temperature.

- 1           2.     The system of claim 1, wherein said fluid processing system is a chemical  
2     processing system.
- 3           3.     The system of claim 2, wherein said fluid is a chemical solution.
- 4           4.     The system of claim 2, wherein said fluid is oil.
- 5           5.     The system of claim 2, wherein said fluid is paper slurry.
- 6           6.     The system of claim 1, wherein said fluid processing system is a biological fluid  
7     processing system.
- 8           7.     The system of claim 6, wherein said fluid is blood.
- 9           8.     The system of claim 6, wherein said fluid is a food product.
- 10          9.     The system of claim 1, wherein said at least one ultrasound probe is calibrated  
11     using an in-factory calibration procedure using at least two test fluids to assess two constants for  
12     converting phase shift measurement to sound velocity, density, or solute concentration.
- 13          10.    The fluid monitoring system of claim 1, wherein said at least one ultrasound  
14     probe is calibrated using an on-line calibration procedure using at least one test fluid injected  
15     into said fluid processing system at a site upstream of said at least one ultrasound probe.
- 16          11.    The system of claim 10, wherein injection of said at least one test fluid into  
17     facilitates quantification of specific solutes in said test fluid by said signal processing unit.
- 18          12.    The system of claim 10, wherein said at least one ultrasound probe is two probes,  
19     said two probes placed in series to measure changes in density due to the passage of said at least  
20     one test fluid.
- 21          13.    The system of claim 1, further comprised of an amplifier, said amplifier  
22     amplifying said receiving signal from said receiving transducer and directing said receiving  
23     signal to said analog-to-digital converter.

1           14.     The system of claim 1, wherein said signal processing unit is built into an IC chip.

2           15.     The system of claim 1, wherein both said emitting signal and said excitation  
3 signal are continuous waves.

4           16.     The system of claim 1, further comprised of a light-emitting mechanism, wherein  
5 said mechanism induces absorbance and/or reflectance of light in said fluid.

6           17.     The system of claim 16, wherein said light-emitting mechanism is an optical  
7 detector, said optical detector comprised of at least one light-emitting diode and at least two  
8 photodiodes.

9           18.     The system of claim 16, wherein said light-emitting mechanism is a  
10 spectrophotometer, said spectrophotometer comprised of at least one light source, at least one  
11 filter, and at least two photomultipliers.

12          19.     The system of claim 16, wherein said computing mechanism uses said density  
13 measurement and said absorbance and/or reflectance measurement to monitor passage of a  
14 specific solute through said fluid processing system.

15          20.     The system of claim 1, further comprising a conductivity/impedance monitoring  
16 device, said device comprised of a pair of electrodes and electronics, wherein said ultrasound  
17 probe works in conjunction with said conductivity/impedance monitor to assess conductivity and  
18 impedance of fluid.

19          21.     The system of claim 20, wherein said computing system uses said density  
20 measurement and said conductivity measurement to monitor passage of a specific solute through  
21 said fluid processing system.

22          22.     The system of claim 1, further comprised of a radioactivity counter and a  
23 radioactivity source.

1           23.     The system of claim 22, wherein said radioactivity counter works in conjunction  
2 with said ultrasound probe to assess radioactivity attenuation of fluid.

3           24.     The system of claim 22, wherein said radioactivity counter works in conjunction  
4 with an optical detector to measure concentration of dye and radioactive tracer in said fluid.

5           25.     The system of claim 1, wherein said at least one ultrasound probe is a clip-on  
6 configuration.

7           26.     The system of claim 25, wherein said probe has no contact with flowing fluid and  
8 imposes no contamination to said fluid.

9           27.     The system of claim 1, wherein said at least one ultrasound probe is a cuvette  
10 configuration.

11          28.     The system of claim 27, wherein said cuvette is placed in a temperature-  
12 controlled environment.

13          29.     The system of claim 1, wherein said at least one ultrasound probe is mounted at  
14 the end of a chromatography column to control collection of specific solutes or a solution  
15 containing no solutes.

16          30.     The system of claim 1, wherein said ultrasound probe is an insertion probe.

17          31.     A system for monitoring density and solute concentration of a fluid in a fluid  
18 processing system comprising:

19                 at least one ultrasound probe comprised of an emitting transducer and a receiving  
20 transducer;

21                 a signal processing unit attached to said at least one ultrasound probe, said unit  
22 comprised of at least a function generator, an amplifier, a dual channel analog-to-digital  
23 converter, and an interface processor;

1                   a computing system adjacent to said signal processing unit, said computing  
2 system receiving digitized signal information from said signal processing unit; and  
3                   a thermistor attached to said ultrasound probe to measure the temperature of said  
4 fluid;  
5                   wherein, said function generator generates a power signal to initiate said emitting  
6 transducer to emit ultrasound wave of specific frequency over a specific time period repeatedly  
7 through said fluid to be received as a receiving signal by said receiving transducer;  
8                   wherein, said analog-to-digital converter digitizes said power signal as an  
9 excitation signal at a specific sampling frequency;  
10                  wherein, said analog-to-digital converter digitizes said receiving signal, said  
11 receiving signal having been received by said receiving transducer at a specific sampling  
12 frequency and amplified by the amplifier;  
13                  wherein, said computing system computes transmission time and phase shift  
14 between said excitation and receiving signals; and  
15                  wherein, said computing system uses said phase shift measurement to compute  
16 sound velocity, density, compressibility, and solute concentration measurements of the fluid at  
17 the measured temperature.

18           32.     A process for monitoring fluid in a fluid processing system, comprising the steps  
19 of:  
20                  calibrating an ultrasound probe in-factory with at least two in-factory calibrating  
21 fluids of known sound velocity to assess phase shift of fluid in terms of sound velocity of said  
22 fluid;

1                   calibrating said ultrasound probe on-line with at least one on-line calibrating fluid  
2   to assess phase shift of fluid in terms of density of said fluid;  
3                   exposing said ultrasound probe into said fluid of said fluid processing system,  
4   wherein said ultrasound probe is comprised of an emitting transducer and a receiving transducer  
5   and is attached to a signal processing unit comprised of at least a function generator, an  
6   amplifier, a dual channel analog-to-digital converter, and an interface processor;  
7                   generating a power signal from said generator, wherein said power signal initiates  
8   said emitting transducer to repeatedly emit over a specific time period an ultrasound wave of  
9   specific frequency through said fluid to be received as a receiving signal by said receiving  
10   transducer;  
11                  digitizing said power signal as an excitation signal via said analog-to-digital  
12   converter;  
13                  amplifying said receiving signal via said amplifier;  
14                  digitizing said amplified receiving signal via said analog-to-digital converter;  
15                  transferring said digitized excitation signal and receiving signal to said interface  
16   processor;  
17                  transferring said digitized excitation signal and receiving signal data to a  
18   computing system, wherein said computing system computes transmission time and phase shift  
19   between said excitation and receiving signals, and wherein, said computing system uses said  
20   phase shift measurement and said calibrating fluid measurements to compute sound velocity,  
21   density, compressibility, and solute concentration measurements of the fluid at a measured  
22   temperature.

1           33.     The process of claim 32, wherein said fluid processing system is a biological or  
2 chemical reactor.

3           34.     The process of claim 32, wherein said fluid processing system is a column of a  
4 liquid chromatography system.

5           35.     The process of claim 32, wherein said fluid processing system is a mixing  
6 chamber.

7           36.     The process of claim 32, wherein said fluid processing system is a cooking vessel.

8           37.     The process of claim 32, wherein said fluid is blood.

9           38.     The process of claim 32, wherein said fluid is a chemical solution.

10          39.     The process of claim 32, wherein said fluid is oil.

11          40.     The process of claim 32, wherein said fluid is a paper slurry.

12          41.     The process of claim 37, wherein said computing system determines density, total  
13 protein content, hematocrit, plasma density, and plasma protein concentration measurements of  
14 said blood.

15          42.     The process of claim 41, wherein changes in blood volume in total circulation and  
16 in microcirculation during a clinical treatment is determined using said measurements and said at  
17 least one test fluid.

18          43.     The process of claim 41, wherein changes in blood volume and pooling of blood  
19 in microcirculation are monitored using said measurements of density and hematocrit of said  
20 blood.

21          44.     The process of claim 32, wherein said calibrating of said ultrasound probe  
22 comprises injecting said at least one calibrating fluid into said fluid of said fluid processing  
23 system upstream of said ultrasound probe.

1           45.     The process of claim 32, wherein said at least one calibrating fluid is two  
2 calibrating fluids.

3           46.     The process of claim 44, wherein said two calibrating fluids have different solute  
4 concentrations.

5           47.     The process of claim 32, further comprised of placing at least two ultrasound  
6 probes in series to measure changes in density due to passage of a test fluid injected upstream of  
7 said ultrasound probes.

8           48.     The process of claim 32, further comprised of monitoring temperature of said  
9 fluid of said fluid processing system, wherein said temperature is used by said computing system  
10 to convert sound velocity measurements of said fluid to density, compressibility, and solute  
11 concentration measurements of said fluid.

12          49.     The process of claim 48, wherein said temperature is monitored using a thermistor  
13 attached to said fluid processing system.

14          50.     The process of claim 32, wherein said computing system uses information from  
15 said ultrasound probe in conjunction with information from a mechanical density measuring  
16 system to convert measurements of sound velocity and phase shift to measurements of density,  
17 compressibility, and solute concentration of said fluid.

18          51.     The process of claim 32, wherein said ultrasound probe is exposed to said fluid of  
19 said fluid processing system in a temperature-controlled environment.

20          52.     The process of claim 32, further comprised of integrating further detection  
21 modality measurements with measurements of said ultrasound probe to monitor passage of a  
22 specific solute through said fluid processing system.



1           53.     The process of claim 52, wherein said detection modality measurement is optical  
2 absorbance and/or reflectance.

3           54.     The process of claim 53, wherein an optical detector determines optical density  
4 from said absorbance and/or reflectance measurement.

5           55.     The process of claim 54, further comprised of on-line calibration of said optical  
6 density measurement of said optical detector with said density measurement of said ultrasound  
7 probe, wherein said at least one test fluid is injected into said fluid processing system.

8           56.     The process of claim 52, wherein said detection modality measurement is  
9 microwave conductivity and/or impedance.

10          57.     The process of claim 52, wherein said detection modality measurement is  
11 magnetic resonance.

12          58.     The process of claim 52, wherein said detection modality measurement is  
13 radiation attenuation.

14          59.     The process of claim 52, wherein said detection modality measurement is tracers  
15 of fluid.

16          60.     The process of claim 52, further comprised of activating of a fractional collector  
17 to collect solution containing most of said specific solute.

18          61.     The process of claim 60, wherein said activating collection of a specific solute  
19 solution improves purity of a specific solute.

20          62.     The process of claim 37 wherein said at least one on-line calibrating fluid is  
21 isotonic saline or dialysate.

22          63.     The process of claim 38 wherein said at least one on-line calibrating fluid is a  
23 base solution.

1           64.     The process of claim 33 wherein said at least one on-line calibrating fluid is  
2     a fluid containing tracers or markers used to assess reaction properties of a chemical or  
3     biological processing system.

4           65.     The process of claim 62, further comprised of diluting said fluid of said fluid  
5     processing system using a dilution procedure wherein a known volume of said saline or dialysate  
6     is infused into said fluid processing system for use in computing blood volume of an animal.